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INTERNETWORKING ISSUES:
BRIDGING LOCAL AREA NETWORKS USING
SYSTEMS OF COMMUNICATING MACHINES

by

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The evolution in network and communication technology has led to the need to interconnect individual computer networks. Network designers are faced with the heterogeneity of networks just as they were previously faced with the heterogeneity of computers within a single network. In interconnecting various types of networks, therefore, many issues must be considered.

This thesis identifies some of these issues as they pertain to the interconnection of two IEEE standards for Local Area Networks, Carrier Sense Multiple Access with Collision Detection (CSMA/CD) and Token Ring. The thesis further discusses a major concern regarding bridging a simplified version of the CSMA/CD and Token Ring protocol using a *system of communicating machines*. The model employs a combination of finite state machines and variables in the specification of each machine. Communication between machines is accomplished through shared variables.

The thesis is concluded by summarizing the issues related to the bridging two Local Area Networks, CSMA/CD and Token Ring, using a system of communicating machines. The advantage this model has over other formal description techniques is briefly described.

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Internetworking Issues:
Bridging Local Area Networks Using
Systems of Communicating Machines

by

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ABSTRACT

The evolution in network and communication technology has led to the need to interconnect individual computer networks. Network designers are faced with the heterogeneity of networks just as they were previously faced with the heterogeneity of computers within a single network. In interconnecting various types of networks, therefore, many issues must be considered.

This thesis identifies some of these issues as they pertain to the interconnection of two IEEE standards for Local Area Networks, Carrier Sense Multiple Access with Collision Detection (CSMA/CD) and Token Ring. The thesis further discusses a major concern regarding bridging a simplified version of the CSMA/CD and Token Ring protocol using a *system of communicating machines.* The model employs a combination of finite state machines and variables in the specification of each machine. Communication between machines is accomplished through shared variables.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

During the latter part of the 1970's, Local Area Networks (LANs) were more a topic of discussion and development in research labs than they were commercial products. However, around 1980 this all started to change due in large part to two important occurrences. The first of these was the introduction of Ethernet, a joint development effort on the part of Digital Equipment Corporation, Intel, and Xerox. Ethernet is a means of connecting computers into a network, and allowing connection between them. The second occurrence was the introduction of the Personal Computer (PC) by IBM in 1981. What followed was an era of continuous innovation in LAN technology.

A. LOCAL AREA NETWORKS

The recent advances in integrated circuit (IC) technology have allowed computers to become smaller in physical size, less expensive, and widely used. In addition, the use of Personal Computers has grown rapidly, leading to an increasing need for PCs to be able to communicate with one another. Moreover, users require more facilities than were available on a single station. They need to be able to access and use facilities available in other stations.

Local Area Networks have been developed to meet these requirements. LANs allow a group of PCs to communicate with one another and to share data and peripheral devices such as a laser printer and a mass storage. Users can easily exchange data and messages, which also means increased productivity. Advanced technology has provided faster and higher-capacity transmission systems capable of carrying large amounts of data.

LANs are usually defined in terms of four characteristics. *A physical medium* is used to carry data signals for transmission. Common media are twisted pair, coaxial cable, and optical fibers.The *transmission technique* determines how the physical medium is used for communication. It deals with signalling scheme in transferring the electrical signal onto the medium. *Topology* includes methods by which network devices are interconnected.

Some of these methods are star, ring, and bus or "tree". The *access control method* or "protocol" allows communicating stations to control access to the transmission medium; this is important since LANs generally allow only one station to transmit at a time.

Although LANs have developed and grown rapidly, the requirements placed on them are increasing beyond the capacity of a single network. This has caused considerable interest in interconnecting them.

B. SCOPE OF THE THESIS

This thesis will cover the issues associated with LAN interconnection, IEEE Local Area Network standards, and the use of a *system of communicating machines* to specify the bridge for connecting LANs.

1. Interconnection Issues

The motivations for building LANs or networks in general (i.e., resource sharing, remote access, and data exchange), are also motivations for interconnecting networks. Network interconnection allows for multiple LANs to be interconnected, so that information can be passed between widely separated locations without restricting local need [Refs. 1,2]. Internetworking also provides a means for extending the physical length of a LAN, thus increasing the number of stations that can be installed on a network.

In general, networks are not compatible with each other. Interconnecting different types of networks can therefore be very complex. Problems common to all interconnections are incompatibility of *frame format*, different *data rates*, and different *frame lengths*. In addition, each pair of interconnected networks has its own unique problems.

To overcome such problems, intermediate devices are required to perform the necessary adaptations or conversions. The generic term for these devices is *gateway* [Refs. 3,4,5,6].

2. IEEE Local Area Networks

[Refs. 7,8] contends that, for several reasons, there will always be a variety of networks. Among these reasons are development of different technologies that will be used in both computer hardware and software. The

leading organization in this area, the Institute of Electrical and Electronic Engineers (IEEE), has developed a set of standards for LANs. These standards have also been adopted by the American National Standards Institute (ANSI) as U.S. national standards, by the National Bureau of Standards (NBS) as government standards, and by the International Standard Organization (ISO) through ISO 8802 standards [Refs. 2,7]. In the IEEE approach, the data link layer is divided into two sublayers : logical link control (LLC) and medium access control (MAC) sublayers. Each of the IEEE 802 standards differs at the physical and MAC sublayer.

3. Systems of Communicating Machines

Network protocols are central to the operation of computer networks, ensuring communication between stations and networks. Because of the important function it serves, specification and analysis of network protocols have become one of the most rapidly growing areas of research computer communication.

Protocol specifications are usually described by four approaches: *informal,* which describes the protocol in terms of natural language, such as English; *transition model,* in which the protocol is described as a set of finite state machines; *abstract program,* which describes the protocol as a parallel program; and *mixed program,* which combines the features of the transition and abstract models [Ref.9]. Of these techniques, the transition model approach is one of the most used and forms the basis for the majority of techniques in protocol specification [Ref. 10].

One such technique is called *systems of communicating machines* [Refs. 11,12], which can be classified as an extended version of a finite state machine. This model uses a combination of finite state machines and variables, either local or shared. Finite state machines and local variables are used to model the station, while communication between stations is performed through shared variables. To determine when the transition might be performed and what action should be taken, the model is accompanied by a predicate action table.

In this thesis, the model *systems of communicating machines* is used to specify a bridge connecting 2 local area networks: one is the CSMA/CD network, using a bus as a connection medium; and the other is a Token Ring network. These are described in detail in the thesis.

C. ORGANIZATION OF THE THESIS

This chapter has provided an overview of the issues associated with the thesis. The concepts involved in communication network technology will be covered in the second chapter, which will also present LAN technology in more detail. This includes a brief presentation on LAN operating system, LAN standard, and LAN interconnection. Chapter 3 will address two of the IEEE LAN standards. The IEEE 802.3 standard defines CSMA/CD protocol for bus topology [Ref. 13], which is nearly identical to the Xerox Ethernet system. A second standard, IEEE 802.5, defines the Token Ring MAC protocol for ring topology [Ref. 14]. Chapter 4 presents various aspects of bridging LANs. Specific coverage will be the issue in bridging IEEE 802.3 (CSMA/CD) and 802.5 (Token Ring). This discussion is followed by presentation of a bridge using a system of communicating machines. Chapter 5 will summarize the issues related to bridging Local Area Networks using a system of communicating machines. The advantages that systems of communicating machines have over most other models for formal protocol specification and the contribution of the thesis will also be presented.

II. LAN OVERVIEW

A. LAN CONCEPT

1. General

LANs provide a means of communication for PCs, so that information can be exchanged between connected stations. The primary objective is to provide high-speed data transfer among a group of stations within a small area.

a. *LAN Definition*

As in other developing technological areas, the definition of a Local Area Network differs from one source to another. Many definitions have been proposed. IEEE defines LANs as follows :

> A datacom system allowing a number of independent devices to communicate directly with each other, within a moderately sized geographic area over a physical communication channel of moderate data rates [Ref. 1].

This definition encompasses four basic elements that specify LANs. First, a LAN is a communication network that allows a number of independent devices to communicate directly with one another, providing facilities to move data from one device to another. Second, communication occurs within a moderately sized geographic area, which means that the area provided by a LAN is relatively small. LANs are usually confined either to a single building or to several buildings that are relatively close together. Third, communication takes place over a physical communication channel. Last, the communication channels of a LAN support a moderate data rate, the rate varying from one network to another. In practice, the rate is from 1 to 10 Mbps. However, the

use of fiber optics will soon expand the range. since fiber optics support bit rates of 100 Mbps.

b. Advantages of LAN

Some of the advantages of LANs are :

- Resource sharing. Expensive resources such as laser printers and mass storage can be shared among a group of interconnected system, allowing economy of resources.
- Higher availability of resources through data exchange or remote access to other networks. This increases productivity as data and message exchange becomes easier.
- Better reliability and maintainability through a centralized system.
- Backup of one system by another in case of failure.

The evolution in network and communication technology has led to several different schemes of transmission, access control, and media type that could be used in networking computers. The following section will present three important parameters that largely determine the nature of the Local Area Network, topology, physical characteristics, and access control methods.

2. Topology

Topology, one of the key elements in a LAN's success or failure in performing its task, refers to the manner in which network devices are geometrically arranged and connected. The major classes of LAN topologies are bus, ring, and star. Each of these methodologies has its own particular advantages and limitations in terms of reliability, expandability, and performance characteristics.

a. Bus

Generally, with bus topology, a single cable runs past all the network stations. Each stations are either connected directly to one another or to the trunk line through a short drop cable. All stations continuously monitors the medium. When a message is transmitted, it propagates throughout the medium and is received by all stations. Each station then determines whether to accept the message or simply ignore it based on the address contained in

the message. To prevent several stations from transmitting simultaneously, some type of communication protocol, or media access control (MAC), is needed. The method used is generally called a "polling" or "contention" technique.

b. Ring

In the ring topology, workstations are linked together the same way as in the bus, but it is arranged to form a loop (ring structure). With this structure, messages are transmitted from station to station around the ring. To transmit, the sending station places a message on the medium. This message then travels around the ring until it either reaches the destination station or is returned to the sender. The interface attachment on each station has the ability to determine whether to accept and process the received message based on the address contained in it. Otherwise, the station will retransmit the message to the next station until it reaches the destination address. Furthermore, the interface also has the ability to remove the message returned to the sender.

c. Star

A star configuration features a central hub to which a collection of stations is directly connected. Communication between any two stations is achieved through the central hub, which is responsible for managing and controlling all communication with active or passive devices.

With an active device, the central hub acts as a switching device. When one station wishes to communicate with another, the hub establishes a dedicated path between the two stations.

With a passive device, a power splitter is used at the hub of the star to divide the incoming signals among the stations.

3. Transmission Characteristics

Other important LAN parameters are the physical characteristics associated with transmitting bits across the medium. The characteristics fall into two categories : transmission media and transmission techniques.

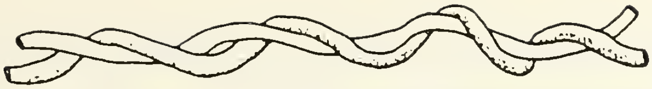
a. *Transmission Media*

The transmission medium provides physical channels needed to connect stations on the network. It is one of the most crucial and complex components of a LAN. Media commonly used for LANs are twisted pair wires, coaxial cable, and fiber optics.

Twisted pair, which has a limited data rate, consists of two insulated copper wires twisted together in a helical form and covered by a common insulated sleeve. Figure 1 illustrates a cable made of twisted-pair wires. Shielded-twisted-wire-pair cable is a special form of twisted pair that uses a higher quality protective sheath. The twisted form is used to reduce electrical interference. It is the most common transmission medium for both analog and digital data, and it is widely used due to their adequate performance and lower cost.

Another common transmission medium is *coaxial cable* (or coax), which consist of a central copper core surrounded by insulating material. The insulator is then surrounded by a cylindrical conductor covered with a protective plastic sheath. Figure 2 shows the construction of a typical coaxial cable. Two kinds of coaxial cable are widely used for LAN application. One type, a 50-ohm cable, is employed for digital signals called "baseband". The other type, a 75-ohm cable, is utilized for analog signaling with Frequency Division Multiplexing (FDM) is called "broadband", and for high-speed digital and analog signals in which no FDM is possible, sometimes referred to as "single channel broadband".

The most exciting development in local network transmission media is the use of *fiber optics*. This medium carries data signals in the form of modulated light beams. An optical fiber structure consists of an extremely thin fiber of glass or fused silica, called "core" surrounded by concentric layers of glass known as "cladding". The outermost layer, surrounding one fiber or a bundle of cladded fibers, is the protective sheath. The construction of a typical optical fiber is shown in Figure 3.



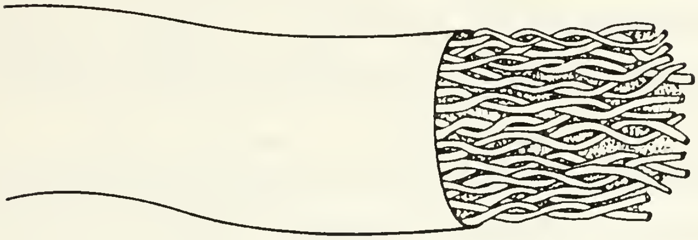


Figure 1. **Twisted-pair cable** [Ref. 1].

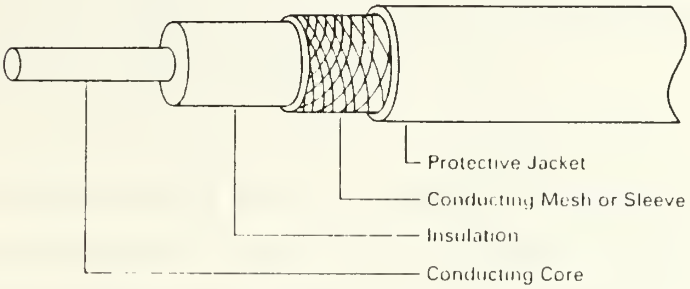


Figure 2. **Coaxial cable** [Ref. 1]

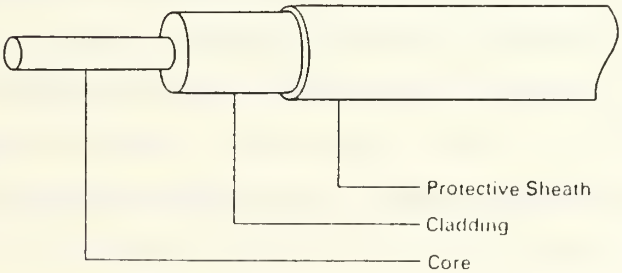


Figure 3. **Fiber Optics** [Ref. 1]

b. *Transmission Techniques*

The various transmission techniques that are implemented within LANs deals with the signalling scheme used to transfer the electrical energy onto the medium [Ref. 15]. Before transmitting the digital information over the medium, it must be electrically encoded in the forms that are distinguishable at the receiving stations. The encoded information is applied to the medium in basically one of two techniques, commonly referred to as baseband and broadband signalling. Equipment can be designed to transmit either digital or analog signals over any of the physical media used in telecommunication.

Baseband uses digital signaling, in which data signals are carried over the physical medium in the form of discrete pulses of electricity. Transmission is bidirectional. The entire frequency spectrum of the medium is used to form the signal, and so FDM cannot be used. Instead, multiple devices attached to a network using baseband transmission share the common channel by means of Time Division Multiplexing (TDM).

Broadband, on the other hand, uses analog signals with a wider range of frequencies than baseband transmission; hence, the use of FDM is possible. With broadband, the transmission is unidirectional and the signal flows across the medium in the form of electromagnetic waves.

4. Access Control Methods

As mentioned above, one of the characteristics of LANs is the use of a transmission medium. Devices on the LAN share the cabling system that connects them, along with the transmission facilities. Thus, it is possible for two or more stations to transmit messages at the same time, causing the signals to interfere with each other. Therefore, a means is needed to determine which station can use the transmission facilities and when. This is the job of the medium access control.

Many access control methods have been derived by the implementers of LAN products. In [Ref. 1] these access control methods are categorized according to whether access control is random, distributed, or centralized.

With *random transmission control*, any station is allowed to transmit whenever the transmission medium is available. Specific permission is not required, but the station might need to sense the availability of the medium before beginning to transmit. Included in this category are Carrier Sense Multiple Access and Collision Detection (CSMA/CD), register insertion, and slotted ring.

In *distributed transmission control*, only one station has the right to transmit at a time, and this right is passed from station to station. Two common access control methods using this technique are token passing and Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

The access control methods that employ a *centralized approach* assume that one station controls the entire network. This station has the authority to direct the use of facilities by other stations, which must request permission from the controlling station before transmitting. Approaches in this category are polling. circuit switching and TDM.

B. LAN OPERATING SYSTEM.

Though LANs are usually defined in terms of topology, media. and access procedure, it is the software that can make or break a network. Quite simply, it is networking software that makes distant resources local. This function relates to the higher-level networking layers and is widely known as *Network Operating System*.

Ideally, networking software should be invisible to the end-user. The operating system removes the user from dealing directly with the hardware implementation of the computer. The user recognizes what resources are available but does not care where resources are and how the user are connected to them.

Structurally, networking software is composed of many modules. Most of them reside in the machine that acts as the server of the data, printers, or communications services; but several important modules must be in every workstation or, sometimes, in devices posed between the workstation and the network.

Some network operating systems come in multiple versions, supporting different architectures. For example, one version may support Ethernet and another Token Ring.

C. LAN INTERCONNECTION

1. General

Rapid advances in network and communication technology have increased the need for connecting LANs to cover a wider area. Interconnecting LANs allows information to be passed between widely separated locations without restricting local needs. Furthermore, the ability to reach other users or stations means extending network capabilities far beyond the single network.

Along with the advantages that advanced technology has offered, the proliferation of LANs in industry has resulted in an interoperability dilemma for network users and designers. Network designers are faced with the heterogeneity of networks, just as they were previously faced with the heterogeneity of computers within a single network. The issues of internetworking thus become more important.

2. Major Consideration

Most of the internetworking general problems are related to the parameters that specify the nature of LANs. Network uses different physical medium to carry data signal for transmission; topology which shows the way network devices are interconnected; and access control methods to control access to the transmission medium.

Some other common problems encountered in interconnecting LANs are shown below [Refs. 7, 13, 14, 16]:

a. Frame Format

Each LAN uses a different frame format. As a result, any copying between different LANs requires reformatting, which takes CPU time, requires a new check sum calculation, and introduces the possibility of undetected errors due to bad bits in the bridge's memory. To see how frame format differs,

compare the two frame formats for Token Ring and CSMA/CD shown in Chapter 4.

b. Speed

Networks allow a variety of speeds. As a result, both software and hardware need to manage the difference in speeds. Each of the IEEE 802 standards uses different speeds. The 802.3 (CSMA/CD) allows 1 to 20 Mbps, while the 802.5 standard calls for 1 or 4 Mbps. In practice, 802.3 is 10 Mbps, and 802.5 is 4 Mbps.

c. Frame Length

All three 802 LANs have different maximum frame lengths. This must be considered, since splitting the frame into pieces is out of the question in the data link layer. All protocols assume that the frames arrive, or that they do not.

d. Buffer Parameters

Buffers are another important consideration in connecting LANs, since they can improve the performance of the LAN if allocated properly. In designing a bridge for CSMA/CD and Token Ring, buffer allocation was one of the primary concerns. Before copying data to another side of the bridge, a buffer is needed to store the data temporarily. How big a space will be needed for the local buffer and the question of whether the buffer will be needed when data is sent to another station will be addressed in more detail in Chapter 4.

3. Gateway

Networks can be connected in a number of ways via a device (or pair of devices) generically called a "gateway". This device provides an interface between networks for establishing long-distance communication between stations on the network. Gateway functions may be implemented with separate equipment connected to two or more networks, as well with additional modules in already existing equipment [Ref. 6].

Four common types of gateway are repeaters, bridges, routers, and protocol converters [Ref. 7]. Each approach to network interconnection raises several issues, depending upon the complexity of the job and how similar the

networks are. Some ways in which networks can differ are : frame, packet, message size, addressing scheme, connection or connectionless, timeout system, status reporting, and network access mechanism.

a. *Repeaters*

Repeaters are low-level devices that amplify only electrical signals and are needed to extend cable length. Repeaters simply copy individual bits between similar networks. It is the simplest and the least expensive of interconnection devices.

b. *Bridges*

Bridges is also used to connect similar networks but it is more intelligent then repeaters. Bridges accept an entire frame and then forward it to a different subnet. They can also make minor changes to the frame before forwarding it. For instance, bridges can be an interface between two networks that employ different access control methods. Bridges work in the physical and data link layers.

c. *Routers*

Routers are similar to bridges, except they are found in the network layer. Networks connected by a router can differ from one another much more than those connected by a bridge. Routers can connect networks with incompatible addressing formats. They receive packets of data from LAN media, then reconfigure them before retransmitting.

d. *Protocol Converters*

Protocol converters are found in the transport layer and above. The gateway converts the protocol used in one network to that used in another by replacing messages received from one network with the same protocol semantics sent to another.

D. LAN STANDARD

The objective of the local standard network standard is to ensure compatibility between equipment made by different manufacture such that data communications can take place between the devices with minimum effort on the part of the equipment users or the builders of a system containing the equipment [Ref. 4].

A standard also increases the market for a particular product. This encourages mass production, leading to lower price in scale implementation.

In the continuing effort to accomplish this mission, a number of organizations have become involved in developing LAN standards, such as ISO, ANSI, and IEEE.

ISO is an international agency for the development of standards on a wide range of subjects. A private, voluntary, nontreaty organization, ISO has been active in developing a system interconnection called Open System Interconnection (OSI). The OSI uses a layer approach, in which a set of functions has been allocated to different layers. ANSI is a nonprofit, nongovernment federation of standard-making and standard-using organizations. It is also the U.S.-designated voting member of the ISO. IEEE is the world's largest professional society and the leading organization in the area of standardizing LANs. Its activities are organized under a number of boards, one of which is IEEE standards.

On the other hand, standard tends to freeze technology and there exist multiple standard for the same thing [Ref. 5].

Chapter 3 will discuss in more detail the properties of a standard model developed by the IEEE 802 committee.

III. IEEE LAN STANDARDS

A. GENERAL

The IEEE 802 has defined a network architecture oriented specifically to LAN implementation called the IEEE 802 standard family. The standard was developed to enable equipment of a variety of manufacturers to interface. It is in complete conformance with two layers -- physical and data -- of the ISO-OSI model.

The IEEE 802 standard is organized as follows :

1. 802.1 Overview, Internetworking, and System Management
2. 802.2 Logical Link Control
3. 802.3 CSMA/CD Bus
4. 802.4 Token Bus
5. 802.5 Token Ring
6. 802.6 Metropolitan Area Networks
7. 802.7 Advisory Group for Broadband Transmission
8. 802.8 Advisory Group for Fiber Optics
9. 802.9 Integrated Voice and Data LANs

The architecture of the 802 standard is in the form of three-layer communication : The *physical layer* encompasses basically the same features as the physical layer in the ISO model; while the *media access control* and *logical link control* sublayers correspond to the data link layer.

a. *Physical Layer*

The physical layer encompasses basically the same features in both the IEEE and ISO model. It is concerned with transmitting bits over the transmission medium and detail device attachment. This includes encoding the data into the proper form for transmission, type of signalling, and timing

control of the devices. The IEEE 802 has standardized on three transmission media explained previously.

b. *Media Access Control Sublayer*

Media access control is concerned mainly with controlling the use of the physical medium, since devices on the LAN share the cabling system and other transmission facilities. The IEEE 802 chose CSMA/CD, Token Ring, and Token Bus access control methods for standardization.

c. *Logical Link Control Sublayer*

The logical link control is responsible for medium independent data link functions. It provides an interface for the network layer to access the LAN device. The standard also defined the interface between the LLC sublayer and MAC sublayer.

B. IEEE 802.3 CSMA/CD

1. Overview

The IEEE standard 802.3 defines the CSMA/CD access control method initially developed by Xerox Corporation. CSMA/CD is the most commonly used access method for LANs employing bus topology. This protocol is sometimes described as *listen while talk* . A station that has data to transmit first senses the medium. If the medium is quiet, the station begins transmitting. Otherwise, it waits for a random period of time before trying to transmit.

The following section presents an overview of the IEEE standard 802.3 [Refs. 1,13,17]. In addition, a simplified version of the standard protocol using a system of communicating machines. is also presented.

2. MAC Service Specification

This section specifies the services provided by the MAC sublayer to the LLC sublayer. In [Ref. 13] the service specification of the interface between the LLC sublayer and the MAC sublayer are defined by three service primitives: MA_DATA.request, MA_DATA.confirm. and MA_DATA.indication.

The service provided by the MAC sublayer allows the LLC sublayer to exchange the LLC data units.

MA_DATA.request defines the transfer of data from the local LLC sublayer entity to one or more peer LLC entities. The primitive is generated by the LLC sublayer entity whenever the data are transferred.

The receipt, on the other hand, will cause the MAC entity to append all specific fields of the particular media access method, and pass them to the lower layer.

MA_DATA.confirm provides a response to the LLC sublayer regarding the success or failure of the request. This primitive is generated as a response to the request from the local LLC sublayer entity. The receipt will be unspecified.

MA_DATA.indication defines the transfer of data from the MAC sublayer entity to the one or more LLC sublayer entities to indicate the arrival of a frame to the local MAC sublayer entity. This receipt is also unspecified.

3. Frame Structure

The 802.3 standard defines the frame format for data communication across the network. The format is shown in Table 1 below.

Table 1. CSMA/CD FRAME FORMAT

Preamble	SFD	DA	SA	LENGTH	LLC Data	PAD	FCS

Preamble begins the frame and is used to establish bit synchronization. The preamble pattern is an alternating sequence of 1's and 0's, with the last bit being a 0.

Start Frame Delimiter (SFD) immediately follows the preamble in the bit sequence 10101011. It indicates the start of the frame.

Destination Address (DA) specifies the station(s) for which the frame is intended. Each address field can be either 2 or 6 octets in length, depending on the vendor that implements the network. The first bit is used to identify

whether the destination address is an individual or group, indicated by 0 or 1, respectively.

Source Address (SA) identifies the station that sent the frame. The first bit is reserved and set to 0. The size of the source and destination address must be the same for all stations on the network.

LENGTH is a 2 octet field that indicates the length of the data field. The field is used to determine the length of the data field when a PAD field is included in the frame.

LLC DATA contains data units supplied by the LLC sublayer.

PAD consist of octets added to ensure that the frame is long enough for proper collision detection.

FRAME CHECK SEQUENCE (FCS) ends the frame. FCS field uses a Cyclic Redundancy Check (CRC) to determine whether an error has occurred.

4. Media Access Control

a. CSMA/CD Operation

As mentioned above, the most commonly used MAC technique for bus topology is CSMA/CD.

With CSMA/CD, a station wishing to communicate first listens to the medium for a specified period to determine whether another station is currently transmitting a message. If no traffic is detected, the station transmits and continue to listen. If a collision is detected, the station waits for a random interval of time, and tries to transmit the message again. When two or more stations send their messages simultaneously and the result is a collision, the transmitting stations stop transmitting. In this situation, receiving stations simply ignore the garbled transmission, while transmitting stations must wait for an indefinite period before attempting to transmit.

b. CSMA/CD Function

In [Ref. 13] the IEEE 802.3 standard defines the functional capabilities of the MAC sublayer. These functions can be categorized into three functions: *Data Encapsulation/Decapsulation*, *Media Access Management*, and

Data Encoding/ Decoding which is concerned with transmitting and receiving data [Refs. 17,1].

Data encapsulation function, provides for adding information to the beginning and end of the data unit to be transmitted after receiving the frame from LLC sublayer, while data decapsulation function in the receiving station to remove the information before passing the frame up to the LLC sublayer.

Media access management is responsible for controlling the availability of the transmission medium. This includes the action regarding collision.

Data encoding perform the function of translating the bits into the proper electrical signal to be sent across the transmission medium, while data decoding translates it back into the bit stream.

5. Considerations

a. *Message Priority*

Since the CSMA/CD standard is intended for operation under a light load, when response time is short, the standard does not provide for message priority. All messages are processed with the same priority.

b. *Response Time*

The response time of a LAN is the time a message must wait at a station before it can be transmitted. Response time is a function of a network data rate, the load presented by all stations, and the access method.

Under a light load, the CSMA/CD provides short response time, because only a few collisions occur and little time is spent in retransmission. As the load increases, response time increases, since more collisions occur at a higher load. Furthermore, when loading approaches the network's capacity, the maximum response time is very long and difficult to predict [Ref. 13].

c. *Error Rate*

Since collisions and the resultant garbled transmissions occur regularly on CSMA/CD networks, it is difficult to measure transmission error rates on operating networks.

d. Frame Format

Frame format is one of the most important aspects to be considered in interconnecting networks. In connecting 802.3 to 802.5, a bridge must generate priority bits since, 802.5 supports priority while 802.3 does not. Bit order and congestion are other considerations.

e. MAC Protocol

A CSMA/CD access controller does not have to maintain long-term information on the state of the network. There is no requirement for monitor and token management functions. This simplifies the implementation of a MAC mechanism and makes CSMA/CD products relatively inexpensive.

(1) Adding and Deleting Stations. Stations are easily added and deleted simply by activating or deactivating them. Activation allows a station to compete for the bus, and deactivation is not detectable at this level [Ref. 2].

(2) Station Behavior. Stations simply operate as if they have exclusive ownership until a collision changes ownership. A station need only wait for the bus to be available. Once a frame is sent, the station can continue using the bus until a collision occurs.

(3) Performance. A station throughput does not depend on the total number of stations; it depends only on the activity of any other station when a transmission is attempted. As loading increases, throughput begins to decrease, with collisions causing delays in completing operations. CSMA/CD operation is unpredictable over short time intervals, so it is not possible to predict or guarantee a certain level of performance. CSMA/CD imposes a minimum time frame requirement to ensure accurate collision detection. Increasing the transmission speed of the bus may not improve throughput in all cases. Only a change in the size of frames can have an effect, and it may not always be possible to make such an alteration.

C. IEEE 802.5 TOKEN RING

1. Overview

Token Ring is one of the most popular ring access techniques. It is the basis of IBM's main architecture for Local Area Networking, and is one of the access methods selected for standardization by the IEEE 802 committee.

The IEEE 802.5 standard defines the token ring access control method protocol for ring topology. It specifies the frame format and medium access control protocol, and describes the services provided by the MAC sublayer to the network management and LLC sublayer. The IEEE 802.5 standard also defines a physical layer based on the shielded twisted pair and differential Manchester encoding, along with the services provided to the network management and MAC sublayer. The following section presents an overview of the IEEE 802.5 standard [Refs. 1,14,17].

2. Token Ring Protocol

The Token Ring network structure consists of serially connected stations using a physical ring topology. Each node is connected to two other nodes: an *upstream* node from which the data is received, and a *downstream* node from which the data will be transmitted. Information is passed sequentially in one direction from one station to the next and each station acts as a repeater to forward the data.

Among the Token Ring's attractive features is the fact that it is not really a broadcast medium, but a collection of individual point-to-point links that happen to form a circle. A ring is also almost entirely digital. The Token Ring protocol handles maintenance using a monitor that each token has.

The token ring technique is based on the use of a particular bit pattern called a *token*, which circulates around the ring when all stations are idle. Any station wishing to transmit must possess a token. Upon receiving, the station modifies one bit in a token to transform it into a *start of a frame* sequence. The station then appends appropriate data needed to construct a frame, and transmits for a specified time.

The data units travel from station to station around the ring. Each station, while repeating the incoming signal, checks to ensure that the frame's DA field matches the individual address. After the station has completed transmission of its frame and the transmitted frame has returned to the station that originally sent it, the station removes the data unit from the network and initiates a new token to be passed on to the next station so that other stations can transmit their data.

3. Frame Format

This section specifies the format generated by the IEEE 802 committee for the token ring access control method. The format of the transmission frame is shown, and special formats for the token and abort sequence are presented.

The first special format is for the token. It contains an access control field and starting and ending delimiter. It is a means by which the right to transmit is passed from one station to another. The format is shown in the figure below :

Starting Delimiter	Access Control	Ending Delimiter

The other special format, called *abort sequence*, is used to terminate the transmission of a frame prematurely. The abort sequence may occur anywhere in the bit stream. The format is shown in the figure below.

Starting Delimiter	Ending Delimiter

The transmission frame format is shown in Table 2 below. It is used for transmitting both the MAC and LLC messages to the destination station(s).

Table 2. TOKEN RING FRAME FORMAT

SD	AC	FC	DA	SA	INFO	FCS	ED	FS

The following are descriptions of the individual fields in the transmission frame, token, and abort sequence formats:

- *Starting delimiter* (SD): consists of signal patterns to indicate the start of a frame. It also includes nondata values to ensure distinguishability from data.
- *Access control* (AC): consists of a *priority bit* to indicate the priority of the token; a *token bit* to identify whether the frame is token or data: A *monitor bit* to monitor the persistence of the frame; and a *reservation bit* .
- *Frame control* (FC): identifies the type of frame and information frame function.
- *Destination address* (DA): specifies the station(s) for which the frame is intended. This can be individual, group, or broadcast.
- *Source address* (SA): identifies the station that sent the frame. The format and length should be the same as the DA in a given frame.
- *Information* (INFO): contains either a protocol data unit from the LLC sublayer or control operation information from the MAC sublayer.
- *Frame-check sequence* (FCS): is a 32-bit cyclic redundancy check modified by division of the FC, DA, SA, and INFO fields.
- *Ending delimiter* (ED): contains nondata values to indicate the end of the frame. It also includes an "I" bit to identify whether it is the last frame of the transmission and an "E" bit for error detection.
- *Frame status* (FS) : contains an address-recognized bit (A) and a frame-copied bit (C) to indicate whether a frame was successfully received by a destination station.

4. Service Specification

The IEEE 802.5 standard specifies the service specification for the interface between the MAC and the LLC sublayer, the physical layer and MAC sublayer, the MAC sublayer and network management, and the physical layer and network management.

a. The primitives required for the interface between the LLC and MAC sublayer are as follow:

- MA_DATA.request
- MA_DATA.indication
- MA_DATA.confirmation

These services provided by the MAC sublayer allow the local LLC sublayer entity to exchange LLC data units with peer LLC sublayer entities.

b. The services required by the MAC sublayer from the physical layer allow the local MAC sublayer entity to exchange MAC data units with peer MAC sublayer entities. The interface between the MAC sublayer and physical layer is defined in terms of the following primitives:

- PH_DATA.request defines the transfer of data from a local MAC sublayer entity to the physical layer for transmission.
- PH_DATA.indication defines the transfer of data from the physical layer to the MAC sublayer.
- PH_DATA.confirmation provides the response by the physical layer to the MAC sublayer, signifying the acceptance of the PH_DATA.request.

c. The following primitives allow local network management to request services from the physical layer. They thus permit local network management to control the operation of the physical layer.

- PH_CONTROL.request is used to request the physical layer to insert itself into or remove itself from the ring.
- PH_CONTROL.indication is used by the physical layer to inform network management of errors and significant status changes.

d. The services provided at the interface between network management and the MAC sublayer are used by network management to monitor and control the operation of the MAC sublayer. These services are :

- MA_INITIALIZE_PROTOCOL.request is used to reset the MAC sublayer and change MAC operational parameters.
- MA_INITIALIZE_PROTOCOL.conformation is used by the MAC sublayer to indicate the success or failure of the request.
- MA_CONTROL.request is used by network management to control the operation of the MAC sublayer.

- MA_STATUS.indication is used by the MAC sublayer to report errors and significant status changes.
- MA_NMT_DATA.request is the primitive that defines the transfer of data from a local NMT entity to the local MAC entity.
- MA_NMT_DATA.indication defines the transfer of data from the MAC sublayer entity to the network management entity.
- MA_NMT_DATA.confirmation is the primitive sent by the MAC sublayer to indicate the success or failure of the requested data. The station that transmits a data unit is responsible for removing the token from the ring while transmitting, and sending a free token to the next station.

5. Physical Layer

The IEEE 802.5 standard defines physical layer specification, including data symbol encoding and decoding, symbol timing, and reliability.

The physical layer encodes and transmits the four symbols presented by the MAC sublayer using a form known as *differential Manchester encoding*. The symbols presented are *binary zero (0)*, *binary one (1)*, *nondata_J (J)*, and *nondata_K (K)* [Refs. 1,14,17]. present the details of the (differential) Manchester encoding system. The latency buffer is provided by the active monitor with two distinct functions : assured minimum latency and phase jitters condensation.

The standard also specifies the functional, electrical, and mechanical characteristics for baseband transmission using two 150-ohm shielded twisted pair wires. It supports the use of a data rate of 1 or 4 Mbit/s with a tolerance of 0.01% [Ref. 14].

6. Considerations

a. *Message Priority*

The token ring provides up to eight separate priorities of data link traffic. A station can preempt the token and reserve it next, regardless of its physical position on the ring relative to the current token-holder. Preemptions are nested by the order of the priority so that proper succession is maintained.

The nature of the ring permits each station to examine the special frame fields while the frame is being regenerated for further delivery. The access control fields have reservation and priority fields to manage prioritized

frames. The reservation field is used in frames carrying data, while the priority field circulates with the token.

b. *Response Time*

Unlike the response time of CSMA/CD, which is short at light load and increases as the load increases, the response time for a token ring is longer at high load, since a station must wait for the token to come around before transmitting. However, under heavy loads, the increase in response time is proportional to the load, which is both efficient and fair.

c. *Frame Format*

In connecting 802.5 to 802.3, several problems must be considered. The 802.5 frames carry a priority bit that an 802.3 frame does not have. As a result, if two 802.5 LANs communicate via an 802.3 LAN, the priority bit will be discarded. A bridge must reformat the frame. The 802.5 frame has A and C bits in the frame status byte. Another consideration is whether the frame is too long.

d. *Measuring Error Rate*

Since a Token Ring network sends data only when other stations are not transmitting, the number of garbled data messages is a good measure of the error rate. A high error rate is an indication of either an incipient failure in a station or a defective cable.

e. *MAC Protocol*

A token ring access controller is more complex than a CSMA/CD controller. Creating and operating a token-passing protocol requires transmission capacity and time delays for protocol exchanges. Token maintenance represents an additional expense, because the functions are replicated in each MAC interface. A Token Ring has only one active monitor, although other monitors must be available to take over in case of failure.

(1) Adding/Deleting Stations. For the purpose of adding and deleting stations, a Token Ring requires only a test for a duplicate address before joining the ring.

(2) Station Behavior. Stations are well-behaved and fair, in that they surrender the token after a certain time. Predictable response times can be attained because of this stability and predictability. Parameters such as the token-holding time can be adjusted to tune the performance.

(3) Performance. Token-passing performance is a function of the number of active participants. Passing the token through each station increases the delay and reduces the throughput for every station. As loading increases, token-passing performance remains very stable. If each station uses its full time interval with each token, the behavior is the same as time division multiplexing. The operation remains fair in that each station can receive a guaranteed portion of the capacity.

In the ring, the token returns after traversing the ring and all intervening systems. The minimum waiting time is the propagation delay and the processing delay of all other systems. The maximum delay adds to the time intervals that all other systems use for their own transfer.

IV. BRIDGING LOCAL AREA NETWORKS

A. GENERAL

In the previous chapters, the issues leading to the need for interconnecting various types of networks have been identified and several approaches that can be used to interconnect them have been briefly explained. This chapter will discuss one of the approaches, bridges, in more detail, and will give a formal specification of a particular type of bridge: one which connects a Token Ring network with CSMA/CD network.

Like other interconnecting approaches, bridges can be implemented in a separate device but are typically implemented in existing devices on the network. When a station on one network has a message to transmit to a station on a different network, the bridge will receive it. In fact, the bridge will receive all messages on each network to which it is connected. It checks the destination address, and when it recognizes that a message is intended for a station in a different network, it transmits the message to that network. This implementation is called the *store-and-forward* function.

Bridges work at a low communication level and are independent of the network protocol software running on the LANs they connect. This allows higher-level software, such as LAN operating systems and applications, to operate without knowing whether it is on a single, physically distinct network or on many LANs that have been bridged to form a larger, virtual LAN [Ref. 18].

A bridge can be employed to interconnect networks that utilize different protocols at the physical layer, as long as these network use a common protocol at the data link layer. A bridge can also be implemented to connect LANs using different MAC methods, which is the case in this thesis [Ref. 1]. A bridge is used to interconnect CSMA/CD networks with Token Ring networks. Both networks must have compatible implementations of the LLC sublayer, and the bridge station must be able to forward messages at the LLC level.

[Ref. 7] shows the operation of a simple bilateral bridge as illustrated in Figure 4. Suppose that Host A on the CSMA/CD LAN has a packet to send to Host B in the Token bus LAN. Before passing the packet from CSMA/CD network to the bridge, the packet move down to LLC sublayer to get LLC header, then to the MAC sublayer where an 802.3 header is perpended to the packet. This unit is sent to the 802.3 part of the bridge, where the 802.3 header is stripped off. The packet with LLC header is then passed to the 802.4 side, get an 802.4 header and eventually reaches Token bus LAN.

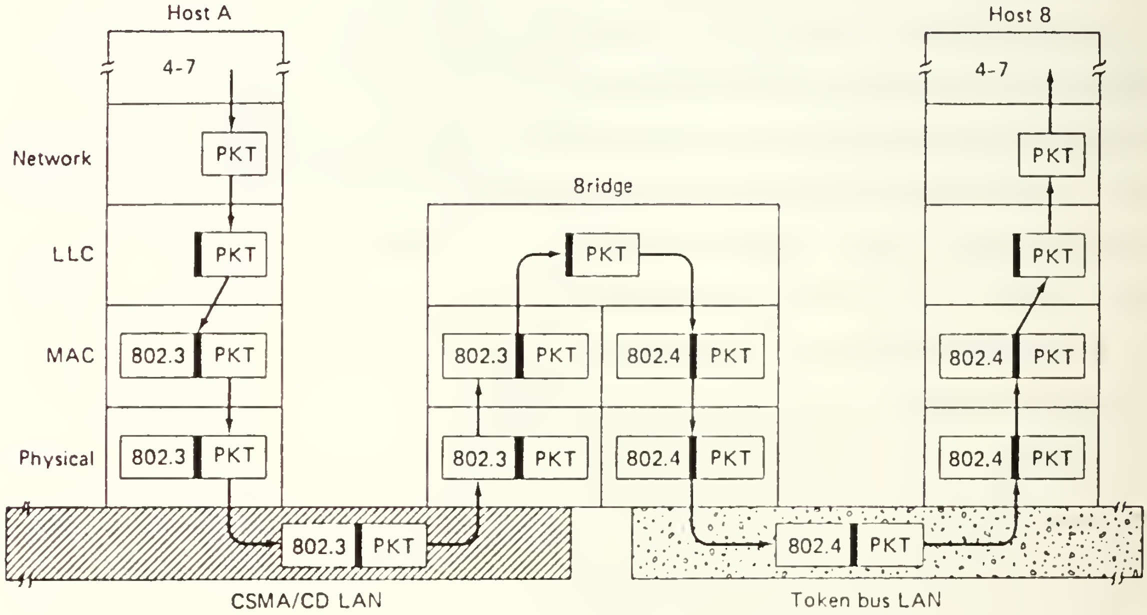


Figure 4. Operation of a LAN's Bridge [Ref. 7].

Several problems common to all interconnecting networks, such as frame format, speeds, and frame length, have been mentioned earlier.

In addition, any interconnection will raise specific problems as a result of the uniqueness of LANs or networks in general. Problems that will be encountered when bridging CSMA/CD and Token Ring are:

- A Token Ring frame format has A and C bits in the frame status (FS) byte that A CSMA/CD frame does not have. These bits are set by the destination address to tell the station originating the frame whether the frame has been recognized and copied.
- A Token Ring carries priority bits while A CSMA/CD does not. As a result, the bridge must generate priority bits when a message is sent by CSMA/CD destined for Token Ring.

B. SYSTEMS OF COMMUNICATING MACHINES

There are three basic approaches to formal protocol specification: *transition, abstract, and hybrid* [Ref. 9]. Each has its particular merits in representation and implementation. One of the most popular techniques for formal specifications is based on the transition model that is represented as a finite state machine [Ref. 10].

One such model is a system of communicating machines, which can be classified as an extended version of a finite state machine. This model uses a combination of a finite state machine (M) and variables (V), either local or shared. Each station is modeled by a finite state machine and variables that are local to the station. Communication between stations is modeled by the use of shared variables. To determine when the transition might be performed and what action should be taken, the model is accompanied by a predicate action table. The standard uses a finite state machine model. but the model employed in the simplified version is precisely defined.

In [Refs. 19, 8] the advantages of a system of communicating machines over most other formal specification techniques has been mentioned. Allowing simultaneous transition makes the modeling of collision in a CSMA/CD network easier. The use of shared variables instead of FIFO queues for communication between machines allows the communication to be modeled as a single variable ethernet bus by all communicating machines.

A system of communicating machines was used to describe and analyze data transfer protocol, with variable window sizes [Ref. 12]. The model was

also utilized to describe the simplified version of IEEE 802.3 (CSMA/CD) [Ref. 8] and IEEE 802.5 (Token Ring) [Ref. 19] standards and will be briefly mentioned in this section. In both application, the algorithm has been simplified but is basically the same as in the standards.

1. Specification of the CSMA/CD Protocol

On the actual CSMA/CD network, the physical communication medium through which communication occurs is called a *bus*. Signals propagate to the end of the bus and are then terminated. A *collision* occurs if two or more stations transmit at the same time.

These three important occurrences are modeled by the use of shared variables, each of which is called a *medium*; the use of a *controller* to clear the medium; and the use of *undefined transitions* that specify the simultaneous write to the medium. For coordination between node and controller an array signal is provided. Each element of this signal may take the value *clear, transceive, or collision* .

The specification of the CSMA/CD protocol are shown in the state machine diagram in Figure 5 and Figure 6, together with the predicate-action tables which appear in Table 3 and Table 4 and the shared and local variables.

Figure 5 depicts the state machine for network nodes. The local variables of each node are *msg*, which is of the same type as *medium*, and *inbuf*, used to receive incoming messages. Predicate action table for the node is shown Table 3. State 0 is the initial state from which either a transmit or receive action is taken. To receive a message, states 0 and 1 will be initiated. States 0, 2, and 3 make up the transmit/collision transitions.

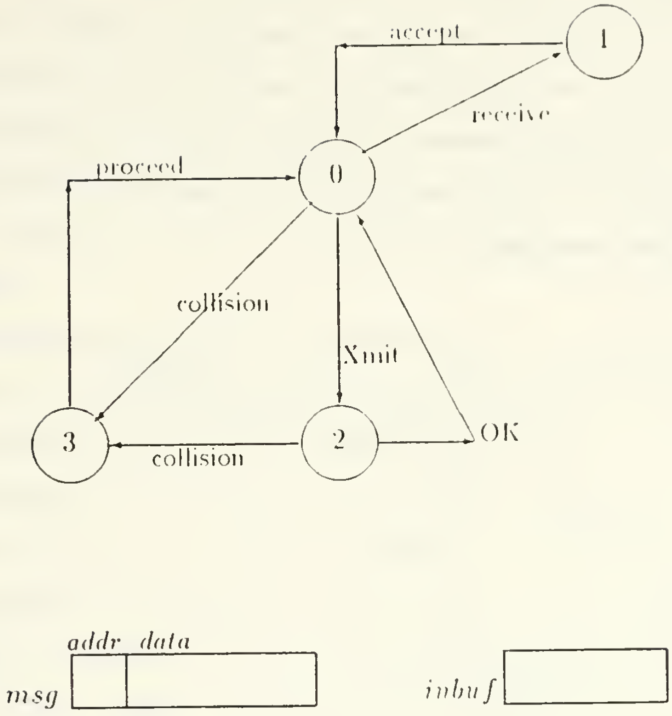


Figure 5. State machine diagram of the CSMA/CD Nodes

Table 3. PREDICATE ACTION TABLE FOR NETWORK NODES

Transition	Enabling Predicate	Action
Xmit	msg $\neq \emptyset \wedge$ medium $= \emptyset$	medium := msg; signal(i) := tranceive
OK	signal(i) = clear	msg := $\emptyset$
collision$\emptyset$	medium = garbage	signal(i) := collision
collision2	medium = garbage $\wedge$ signal(i) = clear	signal(i) := collision
proceed	signal(i) = clear	
receive	medium.addr = i $\wedge$ Signal(i) = clear	inbuf := medium.data
accept		signal(i) := transceive

The state machine of the controller as well as the shared variables are shown in Figure 6. Initially at state 0, the transition can either go to state 2 to delete the garbage, or to state 1 to reset the message. A medium and msg have two parts, [*addr*, *data*]. The address part, *medium.addr*, contains the destination address of the message, and the data part contains the information part of the message. Predicate action tables are provided to show the transition and action that should be taken.

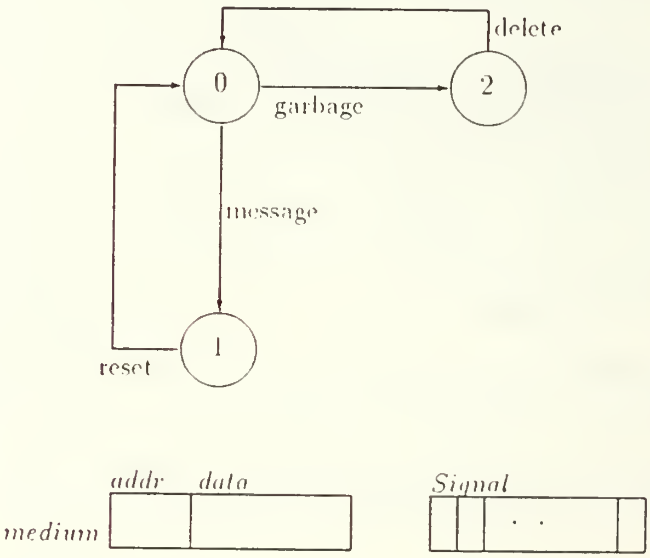


Figure 6. Controller and shared variables

Table 4. PREDICATE ACTION TABLE FOR THE CONTROLLER

Transition	Enabling Predicate	action
message	$\neg$medium $\in$ {garbage,()}	
reset	signal(medium.addr) = tranceive	medium := (); signal(1..n) := clear
garbage	medium = garbage	
delete	signal(1..n) = collision	signal(1..n) := clear; medium := ()

2. Specification of the Token Ring protocol

[Ref. 19] illustrates the application of a system of communicating machines to a greatly simplified version of a Token Ring. It is assumed that no errors occur in transmission and that all messages have equal priority. The buffer is assumed to have a capacity that can hold the largest frame transmitted on the ring and only one frame is transmitted before the token is given up. Furthermore, no attempt is made to model the timing and there is no active or standby monitor.

In the simplified version, the transmitted units are characters, while the standard transmission units are *binary 0*, *binary 1*, *nondata J*, and *nondata K*. Two types of messages are transmitted: *token* and *frame*

Token messages are in a sequence of three characters [J,T,K]; frame messages take the form [J, F, DA, SA, INFO, K, C]. J and K are special characters that signal the beginning (J) and end (K) of the message. They are not allowed inside a message. DA and SA fields indicate the destination and source address, while the INFO field specifies a sequence of characters. The C bit is the "frame copied indicator" through which acknowledgment of messages is accomplished.

The specification of the Token Ring protocol consists of the state machine diagram in Figure 7, together with the predicate action table which appears in Table 5

The state machine diagram in Figure 7 can be considered as two parts. In the left part, states 0-4, no PDU is queued; in the right states 5-15, a PDU has been queued for transmission. State 0 is the initial state, in which incoming messages are repeated to the downstream station. When queueing of a PDU occurs, the transition from state 0 to 5 will be initiated. Compare with predicate action in Table 5 for clarification.

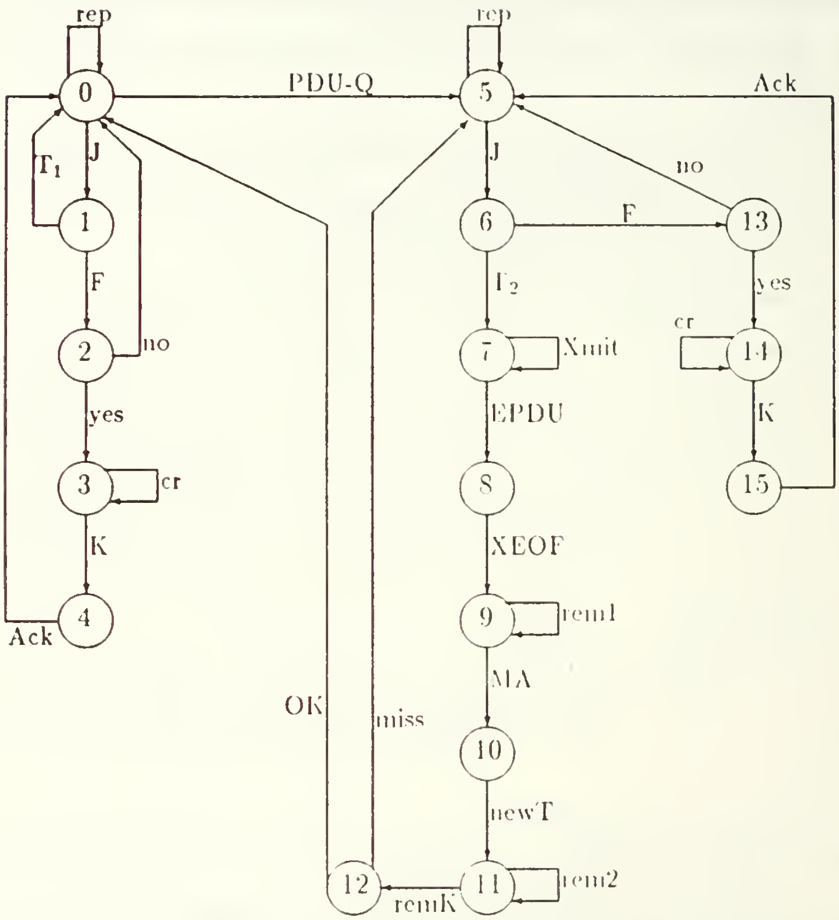


Figure 7. State Machine Diagram for Token Ring Node.

Table 5. PREDICATE ACTION TABLE FOR THE TOKEN RING NODES.

Transition	Enabling Predicate	Action
rep	$\neg$inbuf(i) $\in \{0,J\}$	repeat
PDU-Q	PDU(r) $\neq 0$	
J	inbuf(i) = J	repeat
T1	inbuf(i) = T	repeat
F	inbuf(i) = F	repeat
no	$\neg$inbuf(i) $\in$ {MA, 0} $\vee$cmsgbuf $\neq 0$	repeat
yes	inbuf(i) = MA $\wedge$msgbuf = 0	repeat
cr	inbuf(i) $\neq$ K	msgbuf(m) $\leftarrow$ inbuf(i); inc(m); repeat
K	inbuf(i) = K	repeat
Ack	inbuf(i) = 0	outbuf(o) $\leftarrow$ 1; inbuf(i) $\leftarrow$ 0; inc(o,i)
T2	inbuf(i) = T outbuf(o,o$\oplus$1) $\leftarrow$ (DA,SA); inc(o)	outbuf(o) $\leftarrow$ F; inbuf(i) $\leftarrow$ 0; inc(o,i)
Xmit	PDU(r,p) $\neq 0$	outbuf(o) $\leftarrow$ PDU(r,p); inc(o,p)
EPDU	PDU(r,p) = 0	outbuf(o) $\leftarrow$ K; inc(o); p $\leftarrow$ 1
XEOF		outbuf(o) $\leftarrow$ 0;inc(o)
rem1	inbuf(i) $\neq$ (0$\vee$MA)	inbuf(i) $\leftarrow$ 0; inc(i)
MA	inbuf(i) = MA	inbuf(i) $\leftarrow$ 0;inc(i)
newT	true	outbuf(o,o$\oplus$1,o$\oplus$2) $\leftarrow$(J,T,K); o$\leftarrow$o$\oplus$3
rem2	inbuf(i) $\neq$ K	inbuf(i)$\leftarrow$ 0; inc(i)
remK	inbuf(i) = K	inbuf(i)$\leftarrow$ 0; inc(i)
miss	inbuf(i) = 0	inbuf(i)$\leftarrow$ 0; inc(i)
OK	inbuf(i) = 1	inbuf(i)$\leftarrow$ 0; inc(i); PDU(r)$\leftarrow$ 0; inc(r)

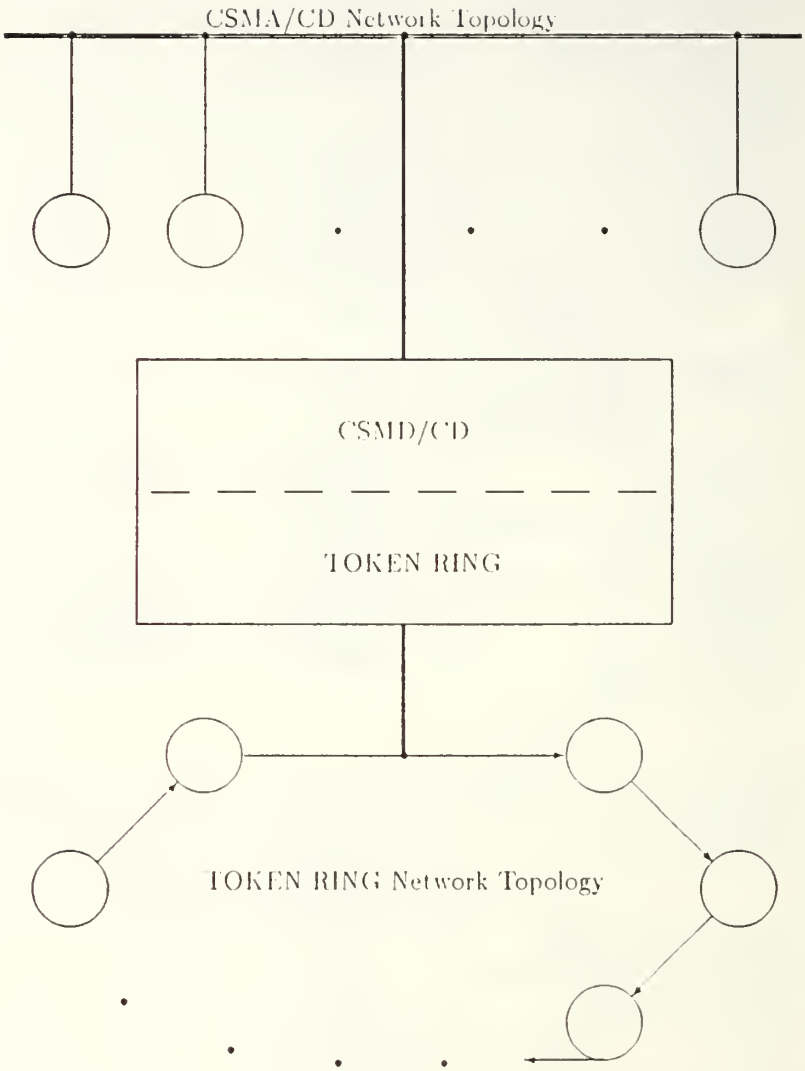


Figure 8. Topology for the Connected Network

C. SPECIFICATION OF THE BRIDGE PROTOCOL

1. General

The purpose of this specification is to illustrate the application of a system of communicating machines to specify a bridge between two IEEE 802 standards for LAN, CSMA/CD and Token Ring networks. Although a Token Ring and CSMA/CD are applied in this specification, the algorithm is basically the as in the standards. In addition, it is assumed that in the operation, the bridge will have highest priority. For instance, there should always be a place in the buffer to copy the incoming message from another network(s). Furthermore, if there are messages in the queue, the one for the bridge will be processed first. Each LAN should be able to perform its regular operation without restricting local needs, but, at the same time, it should be able to communicate with another station on a different LAN.

In the rest of this chapter we will first discuss the specification of the bridge in general, then describe each major part, i.e., the CSMA/CD side, Token Ring side, and Variables. The application of the use of shared variables for communication between nodes, and other properties that the model has, will be demonstrated.

2. Bridge Specification

The specification of the bridge protocol consists of the *state machine diagram* together with a *predicate action table* and the *variables*. Figure 9 depicts the black box of the bridge specification along with all variables used for specification. Figure 8 presents the topology of the CSMA/CD and Token Ring network connected through bridge node. For clarification about topology, refer to LAN overview in Chapter 2.

The state machine diagram for the CSMA/CD and Token Ring side of the bridge are same with the state machine diagram for networks as shown in Figure 5 and Figure 7. They are designed with assumption that, with further work the bridge might be function as both bridge and network station without too many modification. In addition, each edge is labeled with a transition name. Table 8 provides a list of the transition names and their meanings.

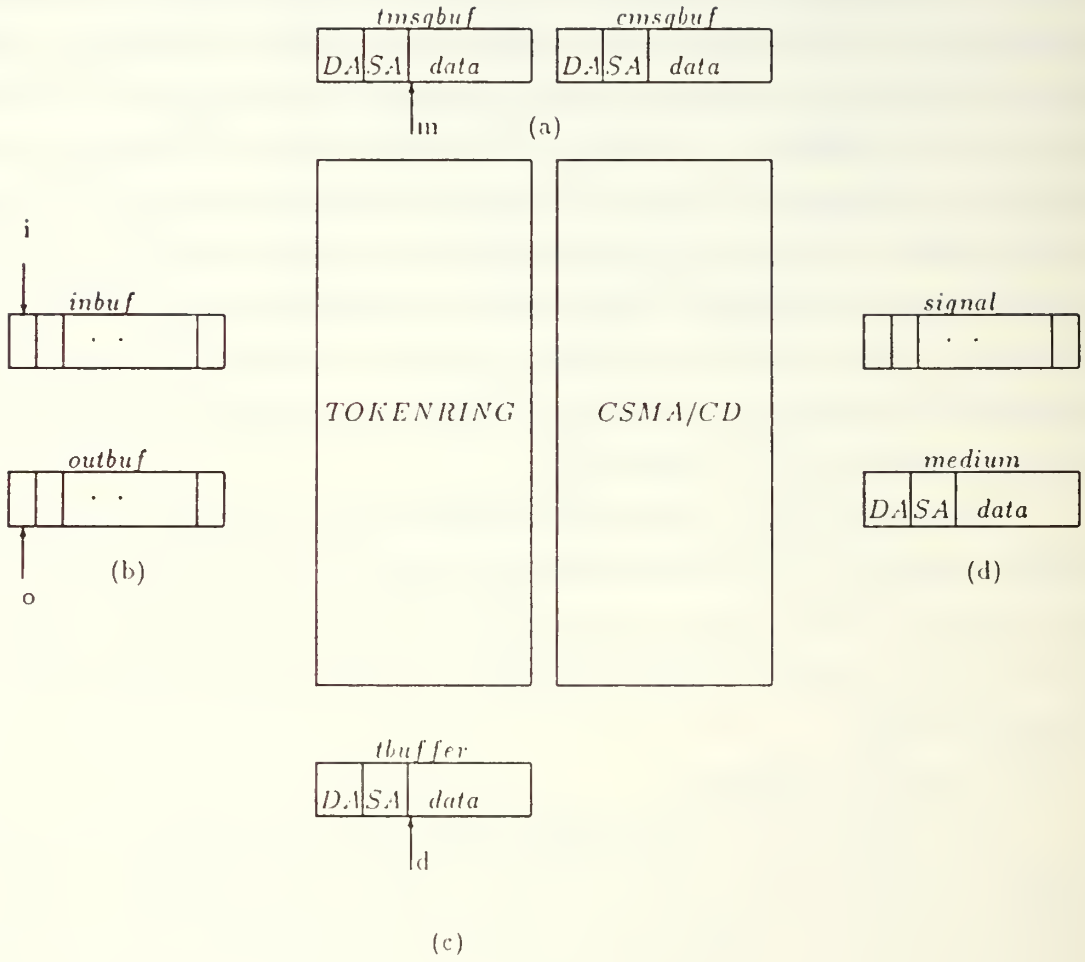


Figure 9. Specification of the Bridge: (a) *cmsgbuf* and *tmsgbuf* are shared variables for the bridge, (b) *inbuf* and *outbuf* are shared with the Token Ring network, (c) *tbuffer* are local variables for the token ring side, and (e) *medium* and *signal* are shared variables with the CSMA/CD network.

The variables shown in Figure 9 are basically categorized into three parts, according to the functions they perform on the network nodes/bridge, either as local or shared variables.

- Variables for the CSMA/CD node consist of:
  Shared variables with the CSMA/CD network (*medium* and *signal*). Medium is actually the network bus, while the signal is used for coordination between the node and controller.
- Variables for the Token Ring node:
  Local variables for the network node (*tbuffer*) are used to receive incoming messages temporarily when tmsgbuf is not available yet. Shared variables with the Token Ring network (*inbuf* and *outbuf*) are used as media for communicating with upstream and downstream stations on the network.
- Shared variables for the bridge (*cmsgbuf* and *tmsgbuf*):
  cmsgbuf is used to receive incoming messages from the Token Ring network. *tmsgbuf* is utilized to receive incoming messages from the CSMA/CD network.
  The predicate action table is presented to show when the transition may be taken and what action should be taken. The predicate action table for the CSMA/CD node appears in Table 6, while the predicate action table for Token Ring in Table 7.

Table 6. PREDICATE ACTION TABLE FOR CSMA/CD SIDE

Transition	Enabling Predicate	Action
Xmit	cmsgbuf $\neq$ () $\wedge$ medium = ()	medium := cmsgbuf;
OK	signal(i) = clear	tmsgbuf := ()
collison()	medium = garbage	signal(i) := collision
collision2	medium = garbage $\wedge$ signal(i) = clear	signa(i) := collision
proceed	signal(i) = clear	
receive	medium.DA = 1i $\wedge$ Signal(i) = clear	tmsgbuf := medium
accept	True	medium := ()

Table 7. PREDICATE ACTION TABLE FOR THE TOKEN RING SIDE

Transition	Enabling Predicate	Action
rep	$\neg$inbuf(i) $\in$ {0,J}	repeat
PDU-Q	tmsgbuf $\neq$ 0	
J	inbuf(i) = J	repeat
T1	inbuf(i) = T	repeat
F	inbuf(i) = F	repeat
no	$\neg$inbuf(i) $\in$ {0s, 0} $\vee$cmsgbuf $\neq$ 0	repeat
yes	(inbuf(i) = 0s) $\wedge$cmsgbuf = 0	tbuffer.DA := 0s; tbuffer.SA := inbuf(i + 1); d := 1; repeat; repeat
cr	inbuf(i) $\neq$ K	tbuffer.data(d) := inbuf(i); inc(d):repeat
K	inbuf(i) = K	cmsgbuf := tbuffer; repeat
Ack	inbuf(i) = 0	outbuf(o) := 1; inbuf(i) := 0; inc(o,i)
T2	inbuf(i) = T;	outbuf(o,o$\oplus$1,o$\oplus$2) := (F,tmsgbuf.DA,tmsgbuf.SA); inbuf(i) := 0; inc(i)
Xmit	tmsgbuf.data(m) $\neq$ 0	outbuf(o) := tmsgbuf.data(m); inc(o,m)
EPDU	tmsgbuf.data(m) = 0	outbuf(o) := K; inc(o); m := 1
XEOF		outbuf(o) := 0; inc(o)
rem1	inbuf(i) $\neq$ (0$\vee$0s)	inbuf(i) := 0; inc(i)
MA	inbuf(i) = 0s	inbuf(i) := 0;inc(i)
newT	true	outbuf(o,o$\oplus$1,o$\oplus$2) := (J,T,K); o := (o$\oplus$3)
rem2	inbuf(i) $\neq$ K	inbuf(i) := 0; inc(i)
remK	inbuf(i) = K	inbuf(i) := 0; inc(i)
miss	inbuf(i) = 0	inbuf(i) := 0; inc(i)
OK	inbuf(i) = 1	inbuf(i) := 0; inc(i); tmsgbuf := 0;

Table 8. MEANINGS OF THE TRANSITION NAMES

Transition	Meaning
rep	repeat character to the next station
PDU-Q	a PDU is queued for transmission
J	first character of frame or token
F	second character of frame
no	no, frame not sent to this station
yes	frame addressed to this station
cr	copy and repeat character to the next station
K	ending delimiter for frame or token
Ack	acknowledgment of frame
Xmit	transmit frame
EPDU	end of protocol data unit
XEOF	transmit end of frame
rem1	remove first part of frame
MA	my address
DA	destination address
SA	source address
newT	transmit new token
rem2	remove second part of frame
remK	remove the K
miss	frame was not received successfully
OK	frame was received
collison0	collision recognized before transmission
collison2	collision recognized after transmission
proceed	medium is clear
receive	get message from the medium
accept	acknowledge the message
message	medium is not empty
reset	clear the medium
garbage	garbage in the medium
delete	collision occurs, delete message

3. Bridge Operation

As explained above, bridges provide an interface between networks. Their functions may be implemented with separate equipment connected to two or more networks, as well as with additional modules in already existing equipment. This thesis assumes that the bridge's station is designed to be able to interface between two simplified versions of the IEEE 802 standard network only.

Suppose a station on the CSMA/CD network has a message to be sent to another station in the Token Ring network. (See Figure 5 and Table 6for clarification.) The CSMA/CD part of the bridge will recognize the message because it is the only station with that address (medium.DA = 1i). The receive transition will be permitted if tmsgbuf = 0. It is assumed that tmsgbuf is originally empty and so receive transition will be possible. The node will copy the messages into *tmsgbuf*, and signal the controller by setting *Signal(i)* to *tranceive* and returning to state 0.

On the Token Ring part of the bridge, tmsbuf.DA, originally 1i, will be changed to 0i. which is the actual destination address of the station in the Token Ring network.. The frame with address 0i will not be recognized by the bridge, so the node will forward the message to the downstream station on the network. In Table 7, this action is indicated by transition Xmit where outbuf(o) gets tmsgbuf.data(m). Outbuf then gets K to signal the end of PDU.

A similar approach will be used when a station on the Token Ring network has a frame to be sent to another station in the CSMA/CD network. (see Figure 7 and Table 7 for clarification.) The first character of any message is a J, followed by either T or F indicating whether a token or frame. If a token, the message is ended by a K. If a message is a frame, the F character is followed by DA indicating destination address, SA indicates Source address and sequence of information (INFO). The message is then ended with a K, followed by a C bit to acknowledge the message by the receiving station. The initial state is 0, and it is assumed that initially all buffer variables (*inbuf*, *outbuf*,

PDU, and *tmsgbuf*) are empty. The process of transmitting a message from a station on the Token Ring network to a station on the CSMA/CD network will be enable if cmsgbuf is empty and the destination address is 1i. Both conditions are necessary, otherwise no transition will be initiated. If yes transition is enable, the destination address part of the message will be converted to 0i, which is the actual destination address on the CSMA/CD network. The message is then copied to cmsgbuf and forwarded to the CSMA/CD network.

V. CONCLUSION

A model for communication protocols called *systems for communicating machines* has been used to specify a bridge between two Local Area Networks, Carrier Sense Multiple Access with Collision Detection (CSMA/CD) and the Token Ring Network. Both protocols are very well known and are heavily used. They are two of the three chosen by the Institute of Electrical and Electronics Engineers for standardization [Refs. 13,14] (the other one is the Token Bus [Ref. 16]). The protocols of the networks have also been described using *systems of communicating machines* [Refs. 8,19].

This thesis build upon earlier work which was carried out in the formal modeling protocols. In [Ref. 19], the same model was used to specify and partially analyze a Token Ring network. The CSMA/CD network was also described and analyzed with this model [Ref. 8]. These specifications were used in this thesis as building blocks for the bridge.

The model uses a combination of finite state machines and variables in the specification of the bridge, and the communication between the bridge and network is accomplished through shared variables. The state machine diagram for the CSMA/CD and Token Ring are the same with the state machine diagram for the protocol as shown [Ref. 8] and [Ref. 19]. They are so designed because to each network, the bridge is merely another node. The internal operation of the bridge is invisible to each network.

Two advantages that *systems of communicating machines* has over other formal description techniques (FDTs) have been demonstrated. One is the use of shared variables for communication between two parts of the bridge and between the bridge and the networks. In many FDTs, communication between machines is modeled by FIFO queues. This is not always an appropriate way to model communication. For example in bus network, all machines are connected by the bus and not by FIFO channels between each pair of machines. The use of shared variables rather than FIFO queues seems to be more natural

in the case where communicating machines shared a common medium. This is the case with ethernet bus, in which many processes share common transmission medium.

Another advantage of this model is that it allows simultaneous transitions, which are generally not allowed in other models. In the CSMA/CD protocol simultaneous write to a share variable is used to model the collision.

In the end, it is worth observing that the interconnection of computer networks is a complex problem and is still an open subject for research. In this thesis a bridge between CSMA/CD and Token Ring has been modeled using a *system of communicating machines*, with several simplifying assumptions. By no means is this work complete and perfect. For example, no formal analysis has yet been completed. Future work could include a more detailed specification of the protocol and analysis of the bridge protocol. The primary purpose of this thesis has been to show the usefulness of systems of communicating machines in specifying the bridge between two IEEE 802 standards for Local Area Networks. It is hoped that this effort has shown the applicability of this model to an internetworking protocol, and its potential application to other network protocols.

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